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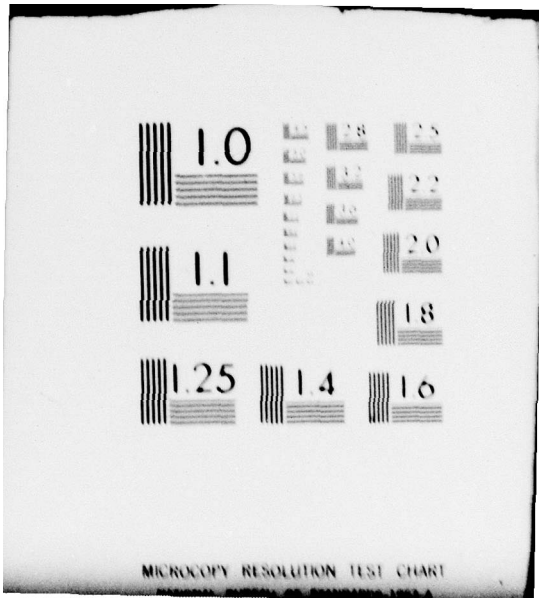
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AIRBORNE NOISE LIMITS FOR MERCHANT SHIPS

Recommended acoustical criteria to insure acceptable functional and habitable environments in crew quarters and work stations

RS Gales

30 April 1979

Prepared for
US Coast Guard
Office of Research and Development
Washington DC 20590

Approved for public release; distribution unlimited

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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Noise criteria are recommended for US merchant ships, based on (1) known noise effects on personnel, (2) existing noise criteria and standards, and (3) a data base of existing shipboard noise levels, augmented by recent measurements aboard seven ships. The recommended criteria are well within the state of the art, assuming the wearing of ear protectors in machinery spaces, additions of enclosed engine control rooms, or both. A set of criteria with an even lower risk of hearing damage and somewhat better habitability is proposed for new ships.

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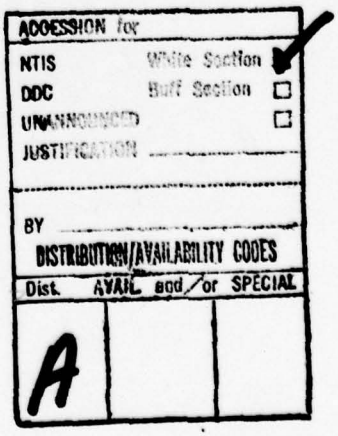
FOREWORD

The contents of this document, including its recommendations, are the responsibility of the author and should not be construed as representing official Navy policy. The author has a background of 25 years of work on criteria for noise and its effects on ships of the US Navy. He also has extensive experience with civilian noise problems, both as an acoustical consultant and by close contact with US and international standardization activity through membership in ANSI and ISO standards working groups.



CONTENTS

SUMMARY

This report presents in a concise form a set of recommended criteria for noise in US merchant ships. The recommendations are based on a combination of (1) knowledge of the effects of noise on personnel, (2) existing noise criteria and standards that are international in scope, and (3) a data base of existing shipboard noise levels. The data base includes recent measurements made aboard US merchant ships specifically for this document. The criteria presented herein are considered to be well within the current state of the art of ship design and construction, assuming that ear protection is worn in machinery spaces. Hearing conservation criteria should be readily achievable in almost all existing ships by the use of currently available ear protection, the addition of enclosed engine control rooms, or both. The criteria recommended by this report, summarized in table 1, will provide an acceptable functional and habitable environment on US merchant ships. Furthermore, on the basis of the very small sample of ships measured, it is believed that current ships could comply with these criteria, assuming that ear protection is worn in machinery spaces. A set of criteria with a lower risk of hearing damage and somewhat better habitability in general is proposed as a goal to be applied to new ships, with an implementation date of perhaps 1985.

Table 1. Summary of criteria recommended in this document.

Noise Effect	Sound Level, dB(A)	
	Immediate	Future Goal
Hearing conservation	$L_{eq24} = 80$	$L_{eq24} = 75$
Speech interference		
Talker, normal voice, distance 2-5 m	60	No change
Talker, raised voice, distance 1-2 m	70	No change
Talker, very loud voice, distance < 1 m or high-level loudspeaker	80	75, to enable lower talker level
Hearing off-ship warning signals	70	65
Recovery from temporary hearing loss	70	65
Rest and relaxation, sleep	65	60

INTRODUCTION

Noise on ships may produce a hazard to the health and safety of the personnel on board and may even pose a threat to the safety of the ship itself under some conditions. This report includes a brief review of the effects of noise on personnel, a summary of existing standards and criteria for acceptable noise on ships, and recommendations for noise limits for merchant ships of the United States.

The information presented herein is the result of an intensive literature search of the effects of noise on humans, of proposed and existing noise standards, and of available published data on noise aboard merchant ships. Additional noise data were obtained specifically for this study by measurements on seven US merchant ships.

For uniformity and ease of comparison throughout this report, A-weighted sound level in decibels (dB(A)) has been used as a single descriptor. This follows a recommendation of Working Group S3–47 of the American National Standards Institute (ANSI) (ref 1) to use A-weighted sound level as a common measure to quantitatively relate levels of sounds to their effects on humans. In this report some criteria are referenced which were originally stated as noise rating numbers (NR) (ref 2). Such ratings have been converted to A-weighted sound level by adding 5 decibels. It is recognized that the difference between NR and sound level in dB(A) depends on the individual spectrum and may vary by several decibels about the 5 dB value; however, 5 dB has been well established for this purpose (ref 3, 4).

EFFECTS OF NOISE

Noise is of critical importance to the safety of personnel and ships because of the following effects.

Hearing Damage

Personnel exposed to high-level noise such as that in engine rooms often suffer hearing loss, particularly when exposed for long periods. Their loss may be temporary or permanent, respectively described quantitatively as decibels of temporary threshold shift (TTS) or permanent threshold shift (PTS). The amount of hearing damage depends on the level and frequency spectrum of the noise, the duration of exposure, the availability of quiet periods for recovery, and the susceptibility of the exposed person. Because of the great variability in susceptibility of individuals to noise-induced hearing loss, it is necessary to base criteria on the concept of protecting a given percentage of the population. It is often presented as a percent risk, which is defined as the percent of exposed persons expected to receive a hearing impairment in excess of that expected in a non-noise-exposed person of the same age.

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1 The Role of ANSI S3–47 (S1) in Coordination of Noise Standards, by RS Gales; Proc of NOISE-CON '75, p 259–266, INCE, 1975.

2 ISO Recommendation R1996, Assessment of Noise with Respect to Community Response, International Standards Organization, 1971.

3 Some Aspects of Noise and Vibration On Board Tankers, by AB Lewis; Noise Control Engineering, vol 7 no 3, p 132, 1976.

4 NTIF Report B0930.4502.1, Noise Control in Ships, by JWE Peterson and JF Storm (ed); Det Norske Veritas, Norwegian Council for Technical and Scientific Research, p 74–84, 1975.

Interference with Speech Communication

Noise interferes with, or masks, the hearing of speech. This is particularly important to the safety and efficient operation of the ship at such locations as the bridge, radio room, engine control room, and wherever commands and other voice communications vital to the operation of the ship must be heard accurately.

Interference with Warning Signals

Noise often masks the audibility of warning signals such as bells and buzzers pertaining to own ship alarms, and it may interfere with hearing off-ship warnings such as whistles, foghorns, diaphones, etc. Quiet is particularly important at the lookout and bridge locations for hearing off-ship warning signals critical to both own-ship and other ships' safety. The high sound level of the own-ship whistle or foghorn may produce a temporary hearing loss which interferes with hearing warning signals.

Rest and Recovery from Temporary Hearing Loss

Noise in rest and relaxation areas such as lounges and sleeping quarters must be low enough to allow adequate sleep and recovery from temporary threshold shift acquired during duty in noisy areas and low enough to prevent adverse noise-related health and physiological effects sometimes observed in human circulatory and nervous systems.

STANDARDS AND CRITERIA

For the first two of those effects (hearing damage and speech interference), which have received much attention, a well-documented body of data is available in the literature on which to base limits. Data on the latter two (warning signals and rest and recovery) are less well established. The following paragraphs discuss existing and proposed criteria for acceptable noise in each of the four categories of effects.

Hearing Damage

Hearing damage risk criteria for industrial noise exposure have been adopted nationally and internationally. These typically are based on A-weighted sound level. They address an 8-hour work day and a 5-day work week, and they assume that the 8-hour work period includes a few short periods during which the worker is removed from the noise. The criteria also assume a quiet environment during off-work hours and weekends. Many nations have established special shipboard noise criteria for engine rooms in addition to the general industrial noise criteria. Rooms containing propulsion and other machinery are the principal ship locations in which noise exposures are sufficient to provide a hearing hazard. An own-ship whistle or horn may under some circumstances create a nearby hearing hazard. Some existing general criteria for hearing conservation are listed as follows:

US OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA) (1971) (ref 5). 90 dB(A) – 8 hours per day. Higher levels are allowed for shorter durations based on 5 dB per time halving up to a maximum level of 115 dB(A) for 15 min. Impulsive

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5 Federal Register, vol 36 no 105, 29 May 1971.

noise may not exceed 140 dB peak. A later proposal (ref 6) recommends extending the criterion to 16 hours at 85 dB(A).

US DEPARTMENT OF DEFENSE (DoD) INSTRUCTION 6055.3 (1978) (ref 7). 80 dB(A) – 16 hours per day; 84 dB(A) – 8 hours per day. Higher levels are allowed for shorter durations based on 4 dB per time halving. Impulsive noise may not exceed 140 dB peak.

US ENVIRONMENTAL PROTECTION AGENCY (EPA) RECOMMENDATION (1974). 70 dB equivalent continuous sound level (L_{eq})* for 24-hour day. Other levels are allowed on the basis of 3 dB per time halving. This gives 75 dB(A) for an 8-hour work day, assuming 16 hours of quiet. This reduces hearing loss to that of a non-noise-exposed population for frequencies essential to the hearing of speech and protects hearing at higher frequencies.

INTERNATIONAL STANDARDS ORGANIZATION (ISO) RECOMMENDATION R1999 (1971). This standard is in the form of a risk table giving the risk of sustaining a noise-induced loss of hearing for speech vs various values of equivalent continuous sound level (L_{eq}) and various total years of exposure. L_{eq} values are for a 40-hour week (eg, five 8-hour days). The table shows that 80 dB L_{eq} produces zero risk for exposures up to 45 years. A level vs time trading relation of 3 dB per time-halving is used. This gives a 24-hour equivalent continuous sound level ($L_{eq}24$) of 75 dB(A) corresponding to the 80 dB work-day level. The risk table shows a 10% risk of hearing loss for 85 dB(A) work-day level (80 dB $L_{eq}24$).

As an aid in relating the above criteria, table 2 summarizes their major characteristics. Figure 1 is a graphic presentation of the level and time relationships for various exposure times and time vs level exchange rates. Some hearing damage risk criteria specifically directed at ships are summarized in table 3. Spaces shown are (1) engine rooms manned continuously, (2) engine rooms manned periodically, such as where an enclosed engine control room exists, and (3) workshops.

Speech Communication

Noise is a major determinant of speech intelligibility, although other factors are also involved. Noise measures often used in describing speech interference are A-weighted sound level, speech interference level (SIL) (an average of the levels in three or four specified octave bands), and the spectrum limit curves. These curves have various shapes and labels, such as noise rating (NR) (ref 2), noise criteria (NC) (ref 8), and preferred noise criteria (PNC) (ref 8). Speech communication criteria are established by specifying the noise which will enable a certain stated probability of correctly understanding speech sounds. The criterion may be given in terms of any of the above measures. The criterion

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* Equivalent continuous sound level (L_{eq}) of a given sound (which may fluctuate in level) is that level of a steady sound which has the same total energy over a specified time duration. This is sometimes called average sound level.

6 Federal Register, vol 39 no 207, 24 October 1974.

7 DoD Instruction 6055.3, 8 June 1978.

8 Noise and Vibration Control, by LL Beranek; McGraw-Hill Book Co, 1971.

value selected depends on (1) talker voice level, (2) distance between talker and listener, (3) difficulty of speech material (unfamiliar vs familiar vocabulary, vocabulary size, and contextual relationships), and (4) accuracy of reception required. Figure 2 is Webster's much-used diagram from which criteria may be selected for various talker-listener conditions (ref 9–11).

Table 2. Summary of general criteria for hearing conservation.

Basic Criteria	8-hour Work Day, dB(A)	24-hour Day Equivalent, dB(A)*	Level Change per Time Halving, dB	Steady-state Noise Limit	Impulse Noise Limit	Risk, % expected to have hearing loss for speech after 40-year exposure**	
						Total	Due to Noise
OSHA: 90 dB(A) per 8 h (ref 5)	90	81	5	115 dB(A) for 15 min or less	140 dB peak	54	21
DOD: 80 dB(A) per 16 h (ref 7)	84	78	4	–	140 dB peak	–	–
EPA: L_{eq24} = 70 dB(A) (ref 12)	75	70	3	–	Based on pulse duration and number per day	33	0***
ISO: Risk table only– based on weekly L_{eq} (ref 13)	80	75	3	–	–	33	0
	85	80	3	–	–	43	10
	90	85	3	–	–	54	21

* Sound level which, if continuous for 24 hours, produces the criterion exposure. Level-time trade is that specific to the criterion. Assumes that level during off-duty period contributes zero to total exposure.

** Based on risk table in reference 13.

*** EPA criterion has margin of safety to protect virtually entire population against PTS greater than 5 dB at 4000 Hz.

9 NOSC Technical Report NELC TR 1314, Speech Interfering Aspects of Navy Noises, by JC Webster and RG Klumpp, 1965.

10 Noise Rating Methods for Predicting Speech Communication Effectiveness, by JC Webster and RS Gales; Transportation Noises, p 85-102, Univ of Washington Press, Seattle, 1970.

11 USEPA Report 550/9-73-008, The Effects of Noise on the Hearing of Speech, by JC Webster; Proc of the International Congress on Noise as a Public Health Problem, p 28, Dubrovnik, Yugoslavia, 13-18 May 1973.

12 USEPA Report 550-9-74-004, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, US Environmental Protection Agency, March 1974.

13 ISO Recommendation R1999, Assessment of Noise Exposure for Hearing Conservation Purposes, International Standards Organization, 1971.

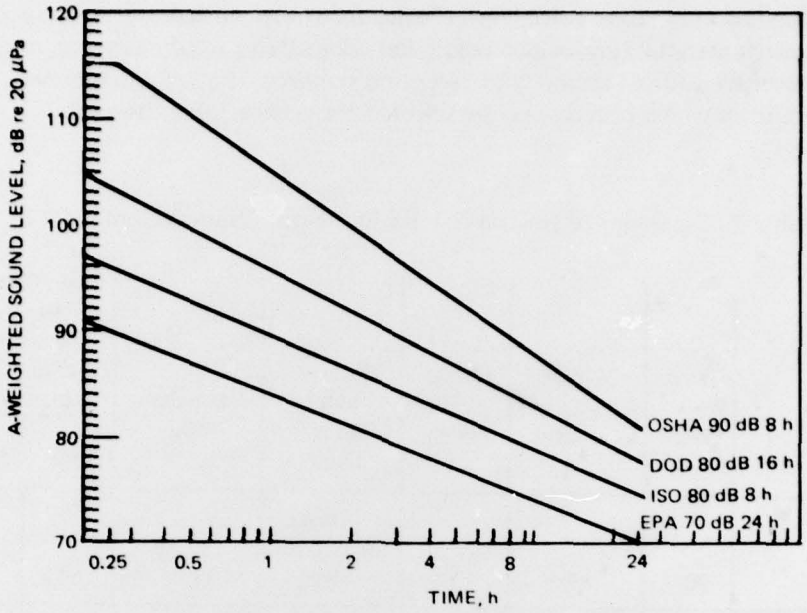

Figure 1. Sound level vs exposure time for various hearing conservation criteria.

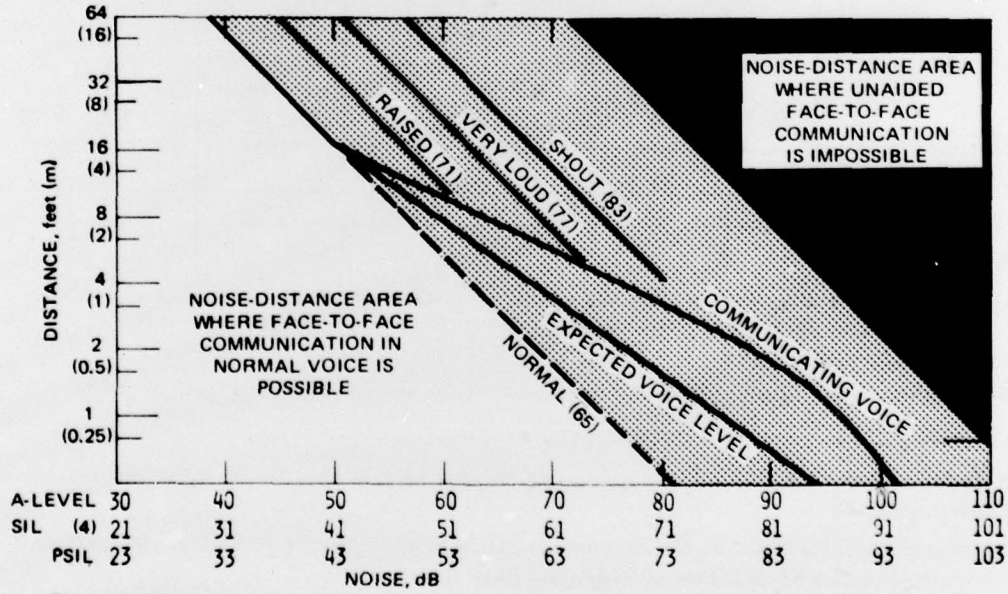

Figure 2. Necessary voice levels as limited by ambient noise for selected distances between talker and listener for satisfactory face-to-face communication (98% sentence intelligibility). Along the abscissa are various measures of noise; along the ordinate, distance; and the parameters are voice level. The three noise measures shown are the A-weighted sound level, the 4-band speech interference level (average level of noise in 4 octaves centered at 0.5, 1, 2, and 4 kHz, and the preferred speech interference level (PSIL) (average level in the 3 octaves centered at 0.5, 1, and 2 kHz). At noise levels above 50 dB(A) people raise their voices as shown by the "expected" line if communications are not vital or by the "communicating" line if communications are vital. (From ref 11)

Table 3. Existing and proposed hearing conservation limits for ships of various flags, based on 8-h workday.

Flag	A-Weighted Sound Level, dB (dB(A))		
	Manned Machinery Spaces	Periodically Manned Machinery Spaces	Workshops
Britain (ref 14)	90	110	90
Denmark (ref 15)	90	110	85
Finland (ref 16)	–	–	–
W Germany (ref 4)	90	110	90
Israel (ref 17)			
existing	90	–	85
new	90	–	80
Netherlands (ref 18)	90	110	90
Norway (ref 4)	90	110	85
Sweden (ref 4)	85	100	75
USSR (ref 19)	80	95	65
USA MARAD draft (1978) (ref 20)	85*	*	85*
Recommended in this report			
Existing ships	85*	110*	85*
Future goal – 1985	80	105	80
US Navy (ref 21)	90	115	90
(ref 7)	84*	–	84*

* Ear protection required in all areas in which the level exceeds 85 dB(A).

14 Code of Practice for Noise Levels in Ships, British Department of Trade, 1977.

15 Noise Level On Board Ships, Denmark; IMCO, 5 January 1978.

16 Highest Permissible Noise Level in Crew Accommodation Aboard Ship, Finnish National Board of Labour Protection, 17 June 1976.

17 Noise Reduction On Board Ships, Israel; IMCO, 8 June 1977.

18 Noise Level On Board Ships, Netherlands; IMCO, 20 July 1978.

19 Noise Levels in Tugs and Other Small Craft, by P Aron; 5th International Tug Convention (1977?), day 2 paper 4.

20 SNAME Project HS-7-1, Ship Vibration and Noise Guidelines (draft), Society of Naval Architects and Marine Engineers, 2 August 1978.

21 NAVSHIPS 0907-004-4010, Steady State Airborne Noise Criteria for Shipboard Spaces, by LA Herstein, 1 April 1970.

Although several alternative noise descriptors are shown in figure 2, experience has shown that A-weighted sound level is accurate and simple to use (ref 10). Properties of the various noise descriptors used for speech interference are described in reference 10. This information has been the source of many criteria, including those used by the US Navy (ref 21). These have been validated over many years of use.

Speech communication criteria are generally stated for a normal or slightly raised voice, but may also be given for telephone use, amplified speech over loudspeaker, and very loud or shouted speech such as may be employed in a machinery control room or maneuvering room. The US Navy has a special "category E" criterion (ref 21) for such situations. Various speech communication criteria are summarized in table 4.

Table 4. Existing and proposed limits for ship spaces in which speech communication is critical.

	A-Weighted Sound Level, dB (dB(A))		
Flag	Engine Control Room	Enclosed Bridge/ Wheelhouse	Radio Room
Britain (ref 14)	–	–	60
Denmark (ref 15)	75	65	65
Finland (ref 16)	–	–	–
W Germany (ref 4)	–	60	60
Israel (ref 17)			
existing	80	70	70
new	75	65	65
Netherlands (ref 18)	80	65	65
Norway (ref 4)	75	65	65
Sweden (ref 4)	70	65	55
USSR (ref 19)	65	55	50
USA MARAD draft (1978) (ref 20)	75	65	60
Recommended in this report			
Existing ships	80	65	70
Future goal – 1985	75	60	65
US Navy (ref 21)	82	60 or 70*	70

*Choice depends on talker-listener distance.

Hearing Warning Signals (Listening Posts)

The establishment of criteria for hearing warning signals is difficult, since the audibility of a signal depends on the specific spectrum of the signal and the specific spectrum of the masking noise at the location of the listener. In general the signal may be expected to be audible if its level in any aural critical band† is equal to or greater than the level of the background noise in the same critical band. In view of the lack of a comprehensive body of data on spectra of warning signals and noise at shipboard listening posts, the criteria presented are simply those which have been adopted or proposed by various sources. These are given in table 5.

Table 5. Existing and proposed limits for hearing warning signals on ships.

Flag	A-Weighted Sound Level in dB (dB(A))	
	Whistle at Listening Posts*	Listening Post Lookout
Britain (ref 14)	110 100**	–
Denmark (ref 15)	–	70
Finland (ref 16)	–	–
W Germany (ref 4)	–	65
Israel (ref 17)		
existing	–	–
new	–	–
Netherlands (ref 18)	110 100**	70
Norway (ref 4)	–	70
Sweden (ref 4)	–	70
USSR (ref 19)	–	–
USA MARAD draft (1978) (ref 20)	–	–
Recommended in this report		
Existing ships	110	70
Future goal – 1985	100	65
US Navy	–	–

*Own ship's whistle limit to prevent excessive temporary hearing loss by lookouts.

**If practicable.

† The aural critical band is the effective analysis bandwidth of the ear (ref 22, chap 1).

22 The Effects of Noise on Man, by K Kryter, chap 12, Academic Press, New York and London, 1970.

Rest and Recovery from Temporary Hearing Loss

Criteria for areas of rest and relaxation must at least allow for recovery of temporary threshold shift (TTS) incurred during duty time. This is necessary to prevent continued TTS that might eventually become a permanent hearing impairment. Sound levels approximating 70 dB(A) or less apparently are not loud enough to impede recovery (ref 23, 24).

Furthermore, criteria for rest and relaxation should be established that prevent the occurrence of appreciable adverse physiological effects. Such criteria are not well established, because the effects are highly dependent on factors other than noise level and frequency content. Intermittency, suddenness of onset, and particularly the meaning of the noise to the listener are typical factors of importance in determining the physiological reaction (ref 12, 22, 25). These issues are too complex and the criteria too uncertain to be addressed here.

Sleep interference is important in establishing criteria for sleeping quarters, hospital areas, etc. Sleep factors are closely related in complexity to rest and relaxation factors. Noise, particularly if it is variable, may affect the quality of sleep by awakening the sleeper or by shifting the stage of sleep from a deep to a lighter state (ref 25). Noise level criteria for sleeping quarters generally comprise the lowest levels of any of the noise criteria. EPA (ref 12) shows a 45 dB(A) average sound level for hospitals. Beranek (ref 8) recommends an indoor L_{50}* of 25 to 50 dB(A) for sleep, depending on whether the location is in country or urban surroundings. He also gives a criterion of L_{NP}** equal to 40 to 65 dB for the same conditions.

Some criteria for ship spaces in which rest and recovery from TTS are especially important are summarized in table 6. In order to group the data into no more than four columns, the column headings in this table have been selected rather arbitrarily as (1) mess/recreation room, (2) offices/day cabins, (3) sleeping cabins, and (4) hospital spaces. Categories (1) and (2) relate mostly to general comfort and recovery from TTS, whereas categories (3) and (4) relate more closely to rest and sleep.

DISCUSSION AND RECOMMENDATIONS

The various existing and proposed ship noise criteria are next reviewed, and criteria are recommended that are considered appropriate to the US merchant fleet. Note that any standard or criterion must be a compromise between desirable end goals and cost. The recommendations below consider both aspects, and in some cases multiple alternatives are provided.

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* L_{50} is the sound level exceeded 50% of the time.

** L_{NP} is noise pollution level, which is L_{eq} plus a correction for the variability of the noise. This correction is a constant (K) times the standard deviation (σ) in decibels. A value of K = 2.56 is used. This makes $L_{NP} = L_{eq} + 2.56\sigma$.

23 Effective Quiet and Moderate TTS: Implications for Noise Exposure Standards, by WD Ward et al; J Acoust Soc Am, vol 59, p 160, January 1976.

24 Long Duration Exposure to Intermittent Noises, by DL Johnson et al; Aviation, Space, and Environmental Medicine, p 987, September 1976.

25 Physiological Effects of Noise, by BL Welch and AS Welch, Plenum Press, New York and London, 1970.

Table 6. Existing and proposed limits for rest, recovery from temporary hearing loss, and sleep on ships.

Flag	A-Weighted Sound Level in dB (dB(A)) Mess/ Rcn Room	Offices/ Day Cabins	Sleep Cabins	Hospital
Britain (ref 14)	65	65	60	60
Denmark (ref 15)	70	65	60	–
Finland (ref 16)	65	60	60	60
W Germany (ref 4)	65	–	60	–
Israel (ref 17)				
existing	80	–	70	–
new	70	–	60	–
Netherlands (ref 18)	65	65	60	60
Norway (ref 4)	–	65	60	–
Sweden (ref 4)	65	65	55	–
USSR (ref 19)	55	–	50	–
USA MARAD draft (1978) (ref 20)	65	60	60	–
Recommended in this report				
Existing ships	70	70	65	65
Future goal – 1985	65	65	60	60
US Navy (ref 21)	70	70	70	65

Hearing Damage

Existing criteria for hearing conservation are based on the normal industrial noise exposure pattern of an 8-hour workday, a 40-hour week. An important factor in the accumulation of a permanent threshold shift is the occurrence of quiet periods with a sound level no higher than 70 dB(A), during which recovery from temporary threshold shift may take place. The normal industrial situation includes a 2-day break each week, a 16-hour break each 24 hours, and, during each work day, a lunch break and several rest breaks. OSHA has stated that its criterion of 90 dB(A) with a 5 dB per time-halving rule is based on the occurrence of several breaks in the workday. A figure of five to seven breaks per day has been given. A good, succinct discussion of hearing damage criteria, including the time vs level trading relation, has been issued by EPA (ref 26).

The exposure of engine-room personnel on merchant ships has a pattern somewhat different from that of typical industrial workers. The normal work day while at sea is 8 hours, but this may be broken into two 4-hour periods separated by 8-hour rest periods. The work week is 7 days, eliminating the 2-day weekend break of the industrial worker. The shorter breaks during the on-duty period may not be effective in recovery from

[26] Federal Register, vol 39 no 244, 18 December 1974.

TTS, since the coffee mess in the engine room area is likely to be as noisy as the rest of the machinery spaces. On the other hand, underway periods with 7-day-per-week duty do not generally last more than 2 weeks, and they are separated by in-port periods of several days during which recovery from TTS may occur. In view of the many and variable factors involved, it is concluded that the two situations are generally comparable in noise hazard, with perhaps the ship condition being potentially of slightly greater hazard, based on the fewer quiet breaks during duty periods.

The recent trend in hearing damage criteria is toward equivalent continuous sound level (L_{eq}) (ref 12, 24). Here a choice must be made among the level-time trading relations. The ISO (ref 13) specifies the equal energy relation (3 dB per time halving), which is considered to be on the conservative side, particularly where the noise exposure is intermittent. The other extreme is the 5 dB per time halving rule of OSHA (ref 1), which assumes the noise exposure to be interrupted about five to seven times per day. Recently the US Department of Defense (ref 7) has adopted the 4 dB per time halving as a compromise. In general, the international prevalence and conservative nature of the ISO-recommended 3 dB rule and its particular relevance to work situations with few quiet breaks suggest adoption of this rule for merchant ships. It is further recommended that the limit be based on the 24-hour equivalent continuous sound level (L_{eq24}) for generality of application, regardless of individual breakdown into duty periods. Two criteria are proposed.

1. For immediate application, a moderately stringent criterion: L_{eq24} of 80 dB, which allows approximately 85 dB for 8 hours accompanied by 16 hours per day in quiet. (This involves about a 10% risk of hearing damage.)
2. For application at a specified future date, a more stringent criterion: L_{eq24} = 75 dB, which allows approximately 80 dB for 8 hours. This should almost eliminate the risk of hearing loss for speech.

Whether commercially available ear protectors can enable ships to meet these standards may be assessed by use of the limited NOSC data base concerning noise on US merchant ships. The NOSC data were taken in accordance with ISO standards (ref 27) on US merchant ships (table 7) of 5000 to 40 000 gross tonnage and 500- to 800-foot length.* They include various ship types and means of propulsion. An analysis based on reducing the measured levels by the expected attenuation of the protector indicates that the initial criterion can be met on current ships by the use of presently available ear protectors, assuming an effective protection of at least 20 dB(A). The wearing of ear protectors should be mandatory in spaces where levels exceed 85 dB(A).

The more stringent criterion, L_{eq24} = 75 dB, allows approximately 80 dB for 8 hours. That this criterion is more difficult to meet on current ships is indicated by NOSC shipboard measurements which showed that even with 20 dB(A) ear protectors, two engineering personnel in one of the seven ships studied would have 24-hour exposures exceeding the 75 dB L_{eq24} by 1 dB. This more stringent criterion, however, has the advantage of providing a degree of protection which assures essentially 100% protection from a noise-induced hearing loss which would handicap hearing of speech. This means that of the exposed crew, none is expected to receive a noise-induced permanent threshold shift (NIPTS) exceeding 25 dB averaged over the frequencies of 500, 1000, and

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[27] ISO Standard 2923, Acoustics – Measurement of Noise On Board Vessels, International Standards Organization, 1975.

*About 5000–40 000 Mg and 150–240 m.

Table 7. NOSC measured levels in ship spaces.

Ship Space	Ship CS 1*	Ship CS 2*	Ship TS 1*	Ship TG 1*	Ship OD 1*	Ship OD 2*	Ship TS 2*
	A-Weighted Sound Level in dB (dB(A))						
Engine room control panel	92	86	94	(8)	(8)	89	91
Max level in machinery spaces	102 (1)	99 (4)	106 (5)	115 (9)	108 (11)	102 (12)	104 (1)
Machinery work shop	91	90	92	–	95	–	–
Engine room control room	(2)	(2)	(2)	56	86	(2)	(2)
Enclosed bridge	60	58	61	56	63	–	64
Open bridge – lookout	73 (3)	68 (10)	–	–	–	–	68-75
Officers' mess	59	58	70	57	68	64	66
Crew's mess	69	58	70	57	69	70	63
Office	54	55	50	57	–	65	62
Officer stateroom	54	53	50 (6) 64 (7)	57	63 (7)	56	62
Crew stateroom	52	53	64	56	66 (13)	64	68

Notes (1) Reduction gear area in engine room.
(2) Ship does not have engine-room control room.
(3) Bow watch station.
(4) Turbine area in engine room.
(5) Stbd generator had noisy reduction gear.
(6) Deck officers.
(7) Engineering officers.
(8) Control area is in control room.
(9) Auxiliary turbine room, max level in ER = 104 in propulsion motor area.
(10) Stbd bridge wing. Port wing = 78 when steam noise from stack is present.
(11) Platform above engines.
(12) Portside of engine near generator in use.
(13) Calculated level (from passageway levels).

*Ship Data
CS 1 General cargo, steam turbine, built in 1960–1965
CS 2 Container ship, steam turbine, built in 1965–1970
TS 1 Tanker, steam turbine, built in 1955–1960
TS 2 Tanker, steam turbine, built in 1970–1975
TG 1 Tanker, gas turbine, built in 1975–1980
OD 1 Ore carrier, twin diesel, built in 1970–1975
OD 2 Ore carrier, single diesel, built in 1920–1925

2000 Hz. Even with this stringent criterion, however, the probability exists that some persons exposed may experience NIPTS at frequencies above 2000 Hz. EPA (ref 12) predicts that the NIPTS of one person in ten will exceed 10 dB at 4000 Hz after a working period of 40 years in this 8-hour, 80 dB(A) environment. This led EPA to recommend a criterion of $L_{eq}24$ = 70 dB or $L_{eq}8$ = 75 dB to protect hearing at all frequencies with a margin of safety. This reasoning would suggest that the $L_{eq}8$ = 80 dB criterion is not too stringent for ships, even though its achievement in machinery spaces may be difficult. It is suggested that consideration be given to establishment of this criterion as a goal for new ships constructed after a specified date. With either criterion, it is important to establish an audiometric monitoring program to identify any beginning hearing loss among engineering personnel.

Speech Interference

Three speech interference criteria are proposed.

1. Most stringent: 60 dB(A), for spaces where speech must be heard very accurately over distances of 2 to 5 metres (bridge, wheelhouse).
2. Intermediate: 70 dB(A), where speech by a raised voice must be heard at distances up to 2 metres (offices).
3. Least stringent: 80 dB(A), for high-level noise spaces where speech is in a very loud voice or is presented via loudspeaker and amplification (engine control room).

Warning Signals

Criteria for audibility of external warning signals such as foghorns, diaphones, etc are difficult to set with certainty because of the variability in spectra of such devices. A background noise upper limit of 70 dB(A) is suggested for listening posts such as outside bridge wings and bow lookout locations. To prevent temporary hearing loss in lookouts, an upper limit at listening posts of 110 dB(A) is proposed for own-ship sounds such as the whistle and horn.

Rest and Recovery from Temporary Hearing Loss

A criterion for spaces for recovery from hearing loss is 70 dB(A); this is sometimes called the level of effective quiet (ref 23). This level, also satisfactory for speech communication at distances up to 2 metres, provides a reasonably comfortable environment for lounges and general relaxation places. Criteria for sleeping accommodations are generally most rigorous of all. These present special problems, since sleep is subject to interruption more by changes in noise than by steady noise. In fact, noise simulating the rushing sound of a ventilation system is often purposely introduced into rooms to mask the noise of outside disturbances. This is sometimes called "acoustic perfume." With this in mind, the 70 dB(A) criterion might also be acceptable for sleeping quarters. In fact, it has been in use in the Navy for many years (ref 21). Navy personnel appear to adapt to such levels with little complaint (ref 28). A level of 65 dB(A) is recommended where sleep and rest

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[28] Noise, You Can Get Used To It, by JC Webster and M Lepor; J Acoust Soc Am, vol 45 no 3, p 751, March 1969.

are most critical, as in hospital spaces. There is no clear advantage in going to lower levels, at which the probability of audible external noise intrusion is increased. Most complaints associated with the seven ships surveyed by NOSC were related to the intrusion of sounds of door slams, machinery noise when passageway-casing doors were opened, voices in passageways, and rattles caused by vibration. Criteria for these and other similar types of noises are difficult to establish. It must be recognized that a level of 70 dB(A) appears to be at the boundary of effective quiet and thus may inhibit recovery for some specific cases involving particular combinations of the background noise spectrum and the frequency distribution of TTS. Since a level of 65 dB(A) would allow a slight margin of safety in recovery from TTS, this is proposed as a future goal, as indicated in table 6.

General Habitability and Comfort

The after portion of many ships is subject to very-low-frequency vibration produced by the propeller and shaft system. This may affect habitability by causing directly sensed vibration, rattling of doors, structure, etc, and the rather unpleasant audible low-frequency sound or "rumble" associated with such vibrations. The frequencies involved are often below 30 Hz, where the response of the A-weighting is of the order of 40 dB or more below that in the 1000–4000 Hz region. This large low-frequency roll-off is appropriate for rating sounds with respect to hearing damage and speech interference but does not adequately rate the discomfort associated with very low frequencies. For example, even though a tanker surveyed in connection with this study had so much vibration in the aft-located officers' mess that silverware vibrated off the table, the A-weighted sound level was only 70 dB. The C-weighted level, measured with a uniform response down to about 30 Hz, was 99 dB. The difference between these C- and A-weighted levels was 29 dB. The C – A difference for any sound is a useful measure of the low frequency content of a sound. Most sounds have a C – A difference between 0 and 15 dB (ref 9). Shipboard sounds in areas of strong low-frequency vibrations often show C – A values of 20 to 30 dB. Although no adverse health effects have been attributed to these low frequencies, it may be desirable to limit them for the sake of general comfort. Such limits may be established by limiting the C- to A-level difference, C-level noise, vibration, or any combination of these. The fact that these characteristics are all related suggests that separate steps to limit all three quantities are probably not needed. Reference 3 discusses vibration criteria and the concept of combined noise-vibration limits. Criteria of this type are not included in this report because data on such criteria are very sparse and the need for such criteria has not yet been adequately studied or documented. This should be an area of future study.

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